

Camera & Image

Dr. Tushar Sandhan

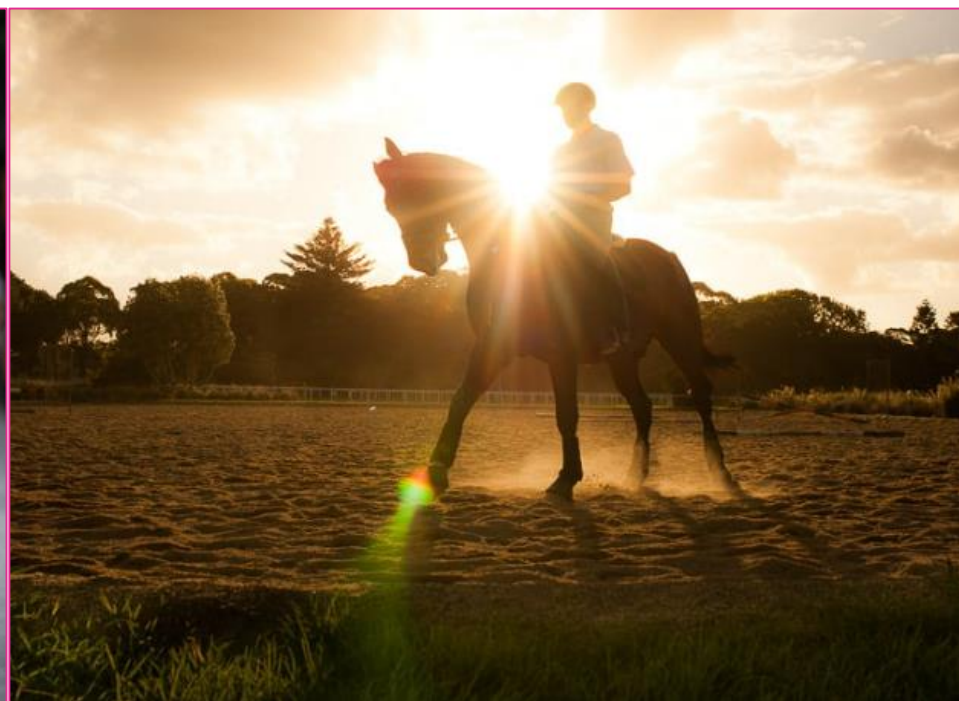
Introduction



Introduction



Introduction

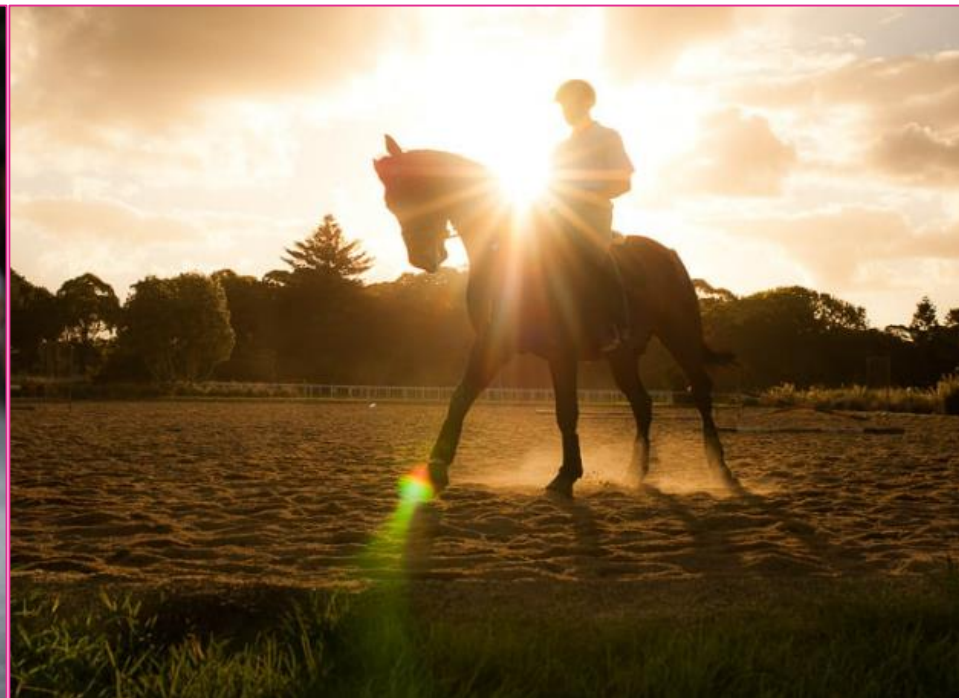


Introduction

○ Focus



○ Colors

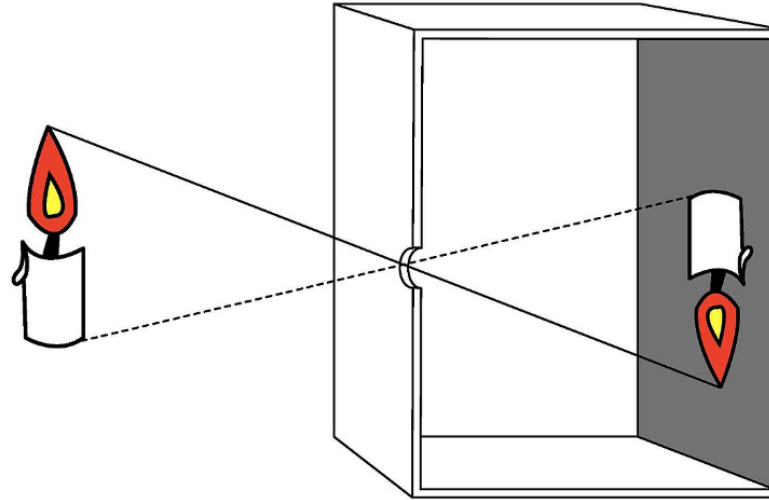


○ Motions



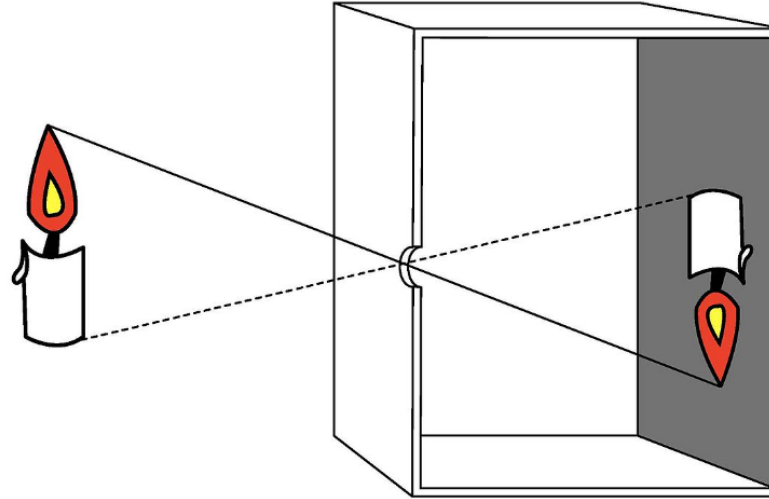
Aperture

- Pinhole camera
 - without lens
 - tiny aperture
 - no lens distortions
 - everything appears in focus
 - ∞ DOF



Aperture

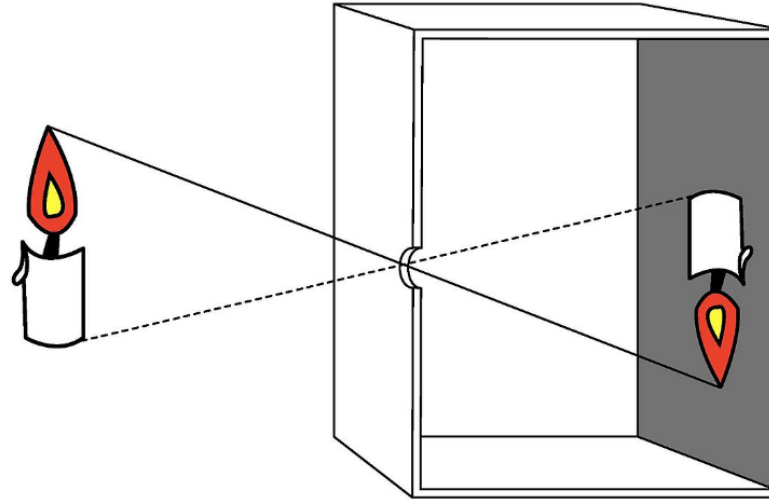
- Pinhole camera
 - without lens
 - tiny aperture
 - no lens distortions
 - everything appears in focus
 - ∞ DOF
- Photography camera
 - controllable aperture



Aperture

- Pinhole camera

- without lens
- tiny aperture
- no lens distortions
- everything appears in focus
 - ∞ DOF



- Photography camera

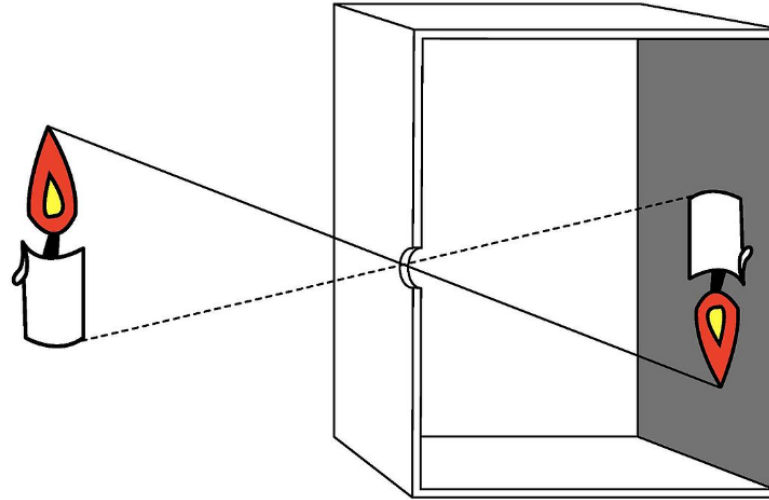
- controllable aperture



Aperture

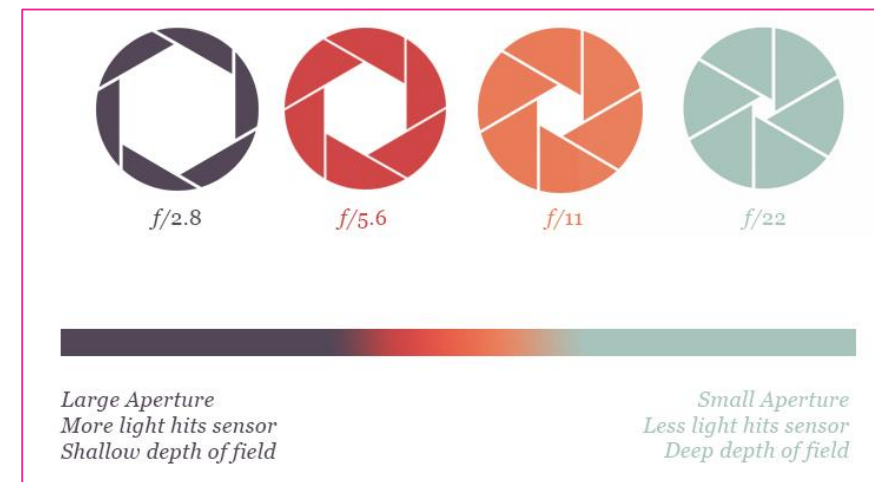
- Pinhole camera

- without lens
- tiny aperture
- no lens distortions
- everything appears in focus
 - ∞ DOF



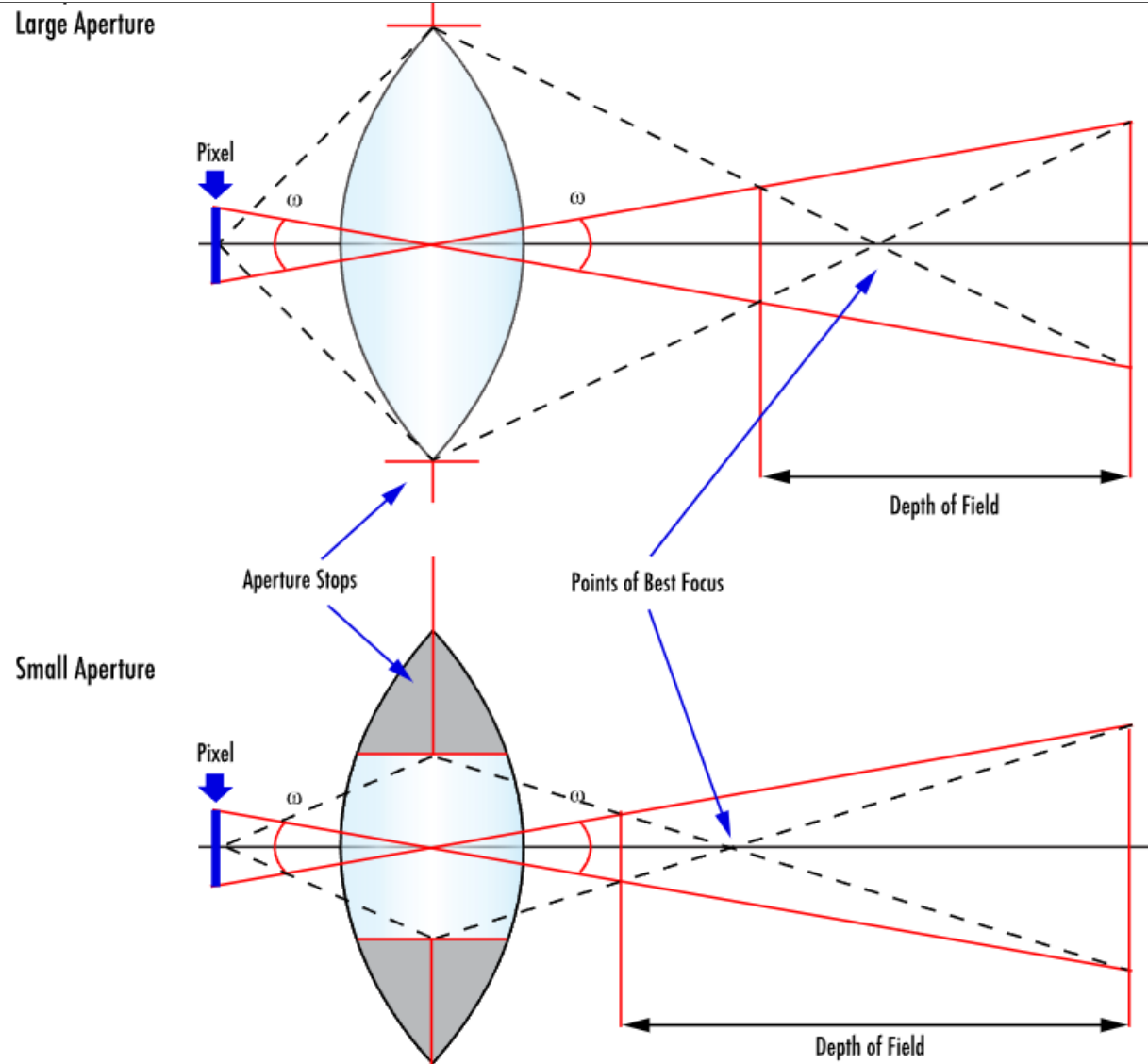
- Photography camera

- controllable aperture



Aperture

- Depth of Field
 - aperture ↓ : DOF ↑



Aperture

- Depth of Field

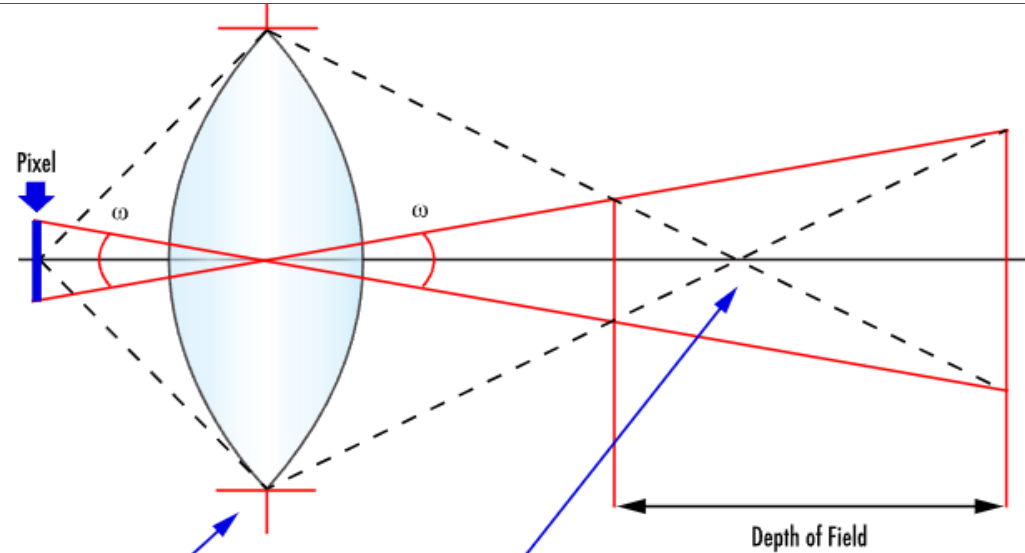
- aperture ↓ : DOF ↑

- Shutter

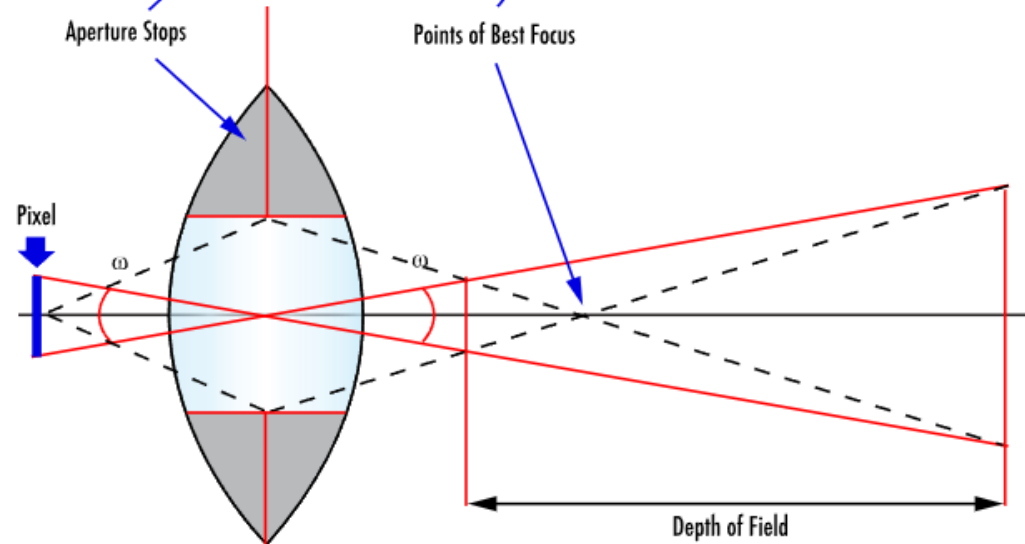
- optical ON OFF

- motion ↑ : speed ↑

Large Aperture



Small Aperture



Sensors

- Passive (self-generated sensors)
 - Not require external power
 - resistors
 - capacitors
 - inductors, transformers
 - antennas
 - diodes

Sensors

- Passive (self-generated sensors)

- Not require external power

- resistors
 - capacitors
 - inductors, transformers
 - antennas
 - diodes

- Active (parametric sensors)

- Require external power

- LED
 - solenoid
 - LiDAR
 - LCD

Sensors

- Passive (self-generated sensors)

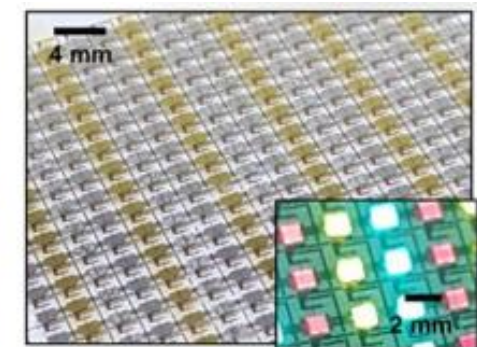
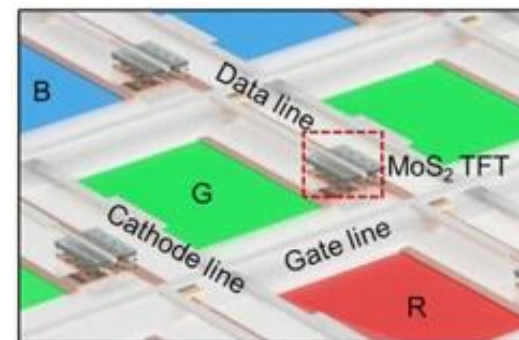
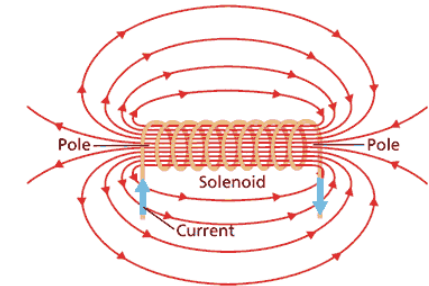
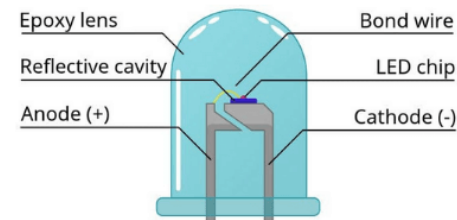
- Not require external power

- resistors
- capacitors
- inductors, transformers
- antennas
- diodes

- Active (parametric sensors)

- Require external power

- LED
- solenoid
- LiDAR
- LCD



Sensors

- Passive (self-generated sensors)

- Not require external power

- resistors
- capacitors
- inductors, transformers
- antennas
- diodes

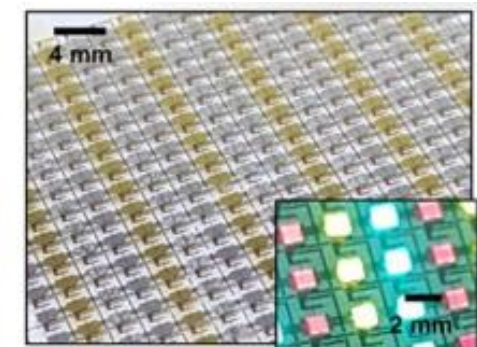
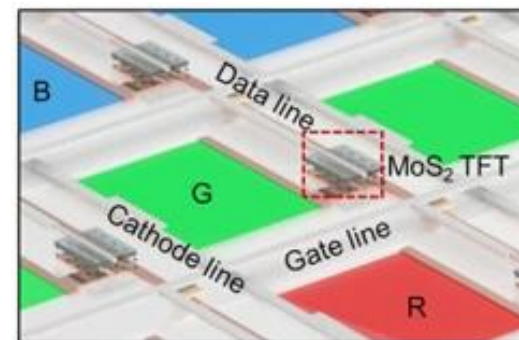
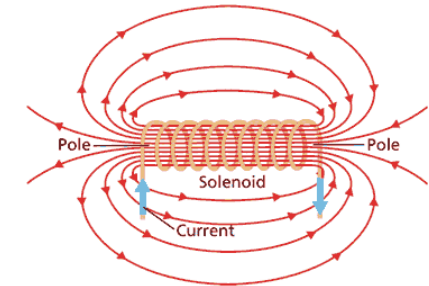
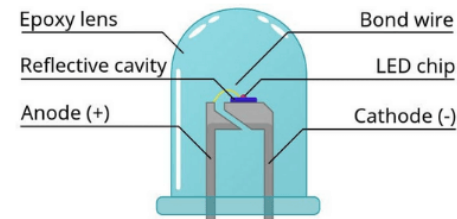
- Active (parametric sensors)

- Require external power

- LED
- solenoid
- LiDAR
- LCD

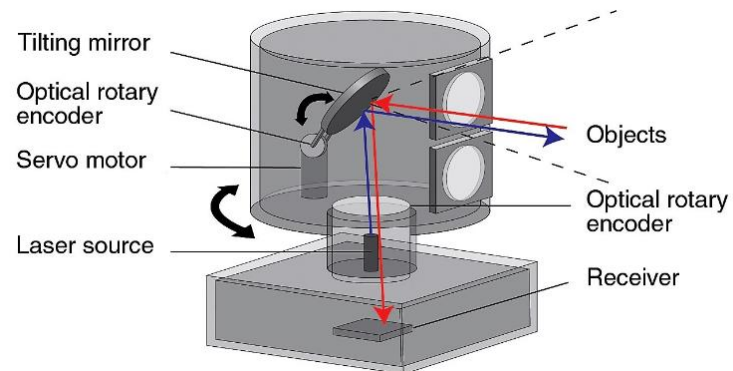
- Which are energetically more efficient?

- Nature's choice



Active sensing

- Precision
 - elevation mapping
- Safety
 - autonomous driving (LIDAR)
 - leader?



Active sensing

- Precision
 - elevation mapping
- Safety
 - autonomous driving (LIDAR)
 - leader?

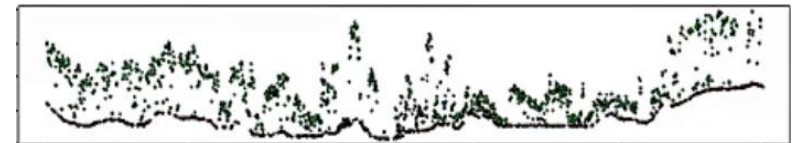
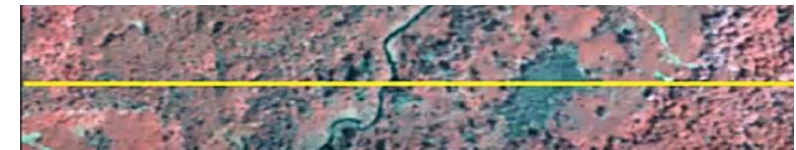
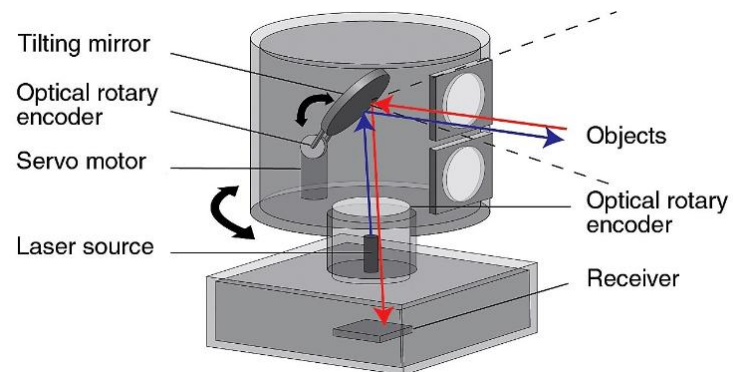
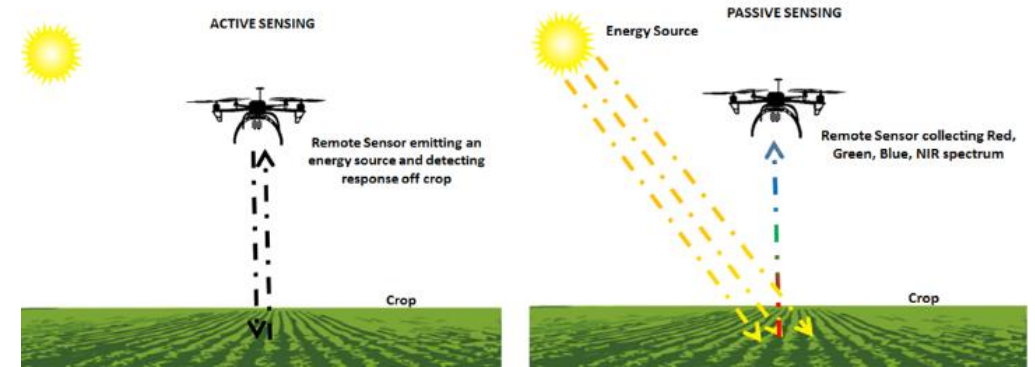


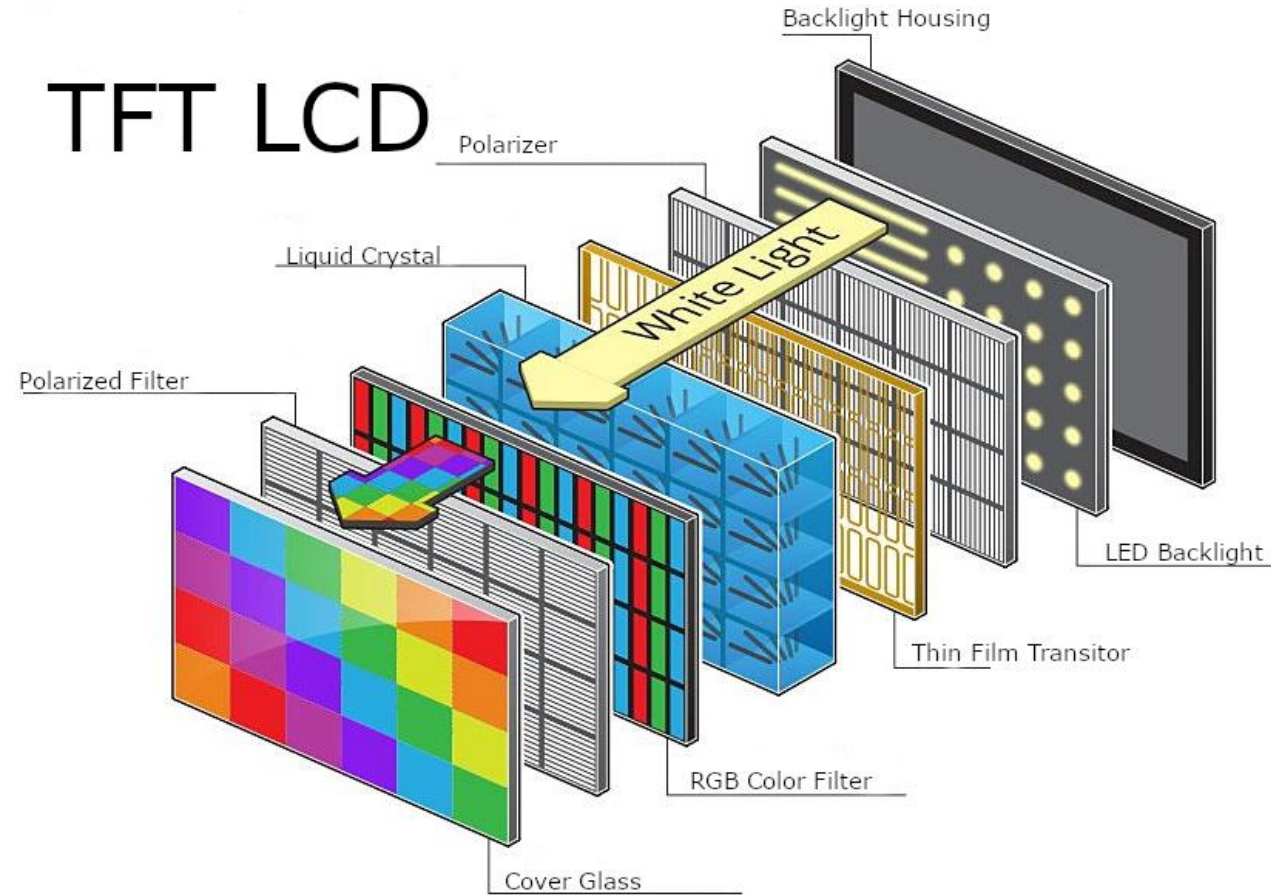
Image display

- Active

- LCD

- twisted nematic liquid
 - rotate the polarization of linearly polarized light

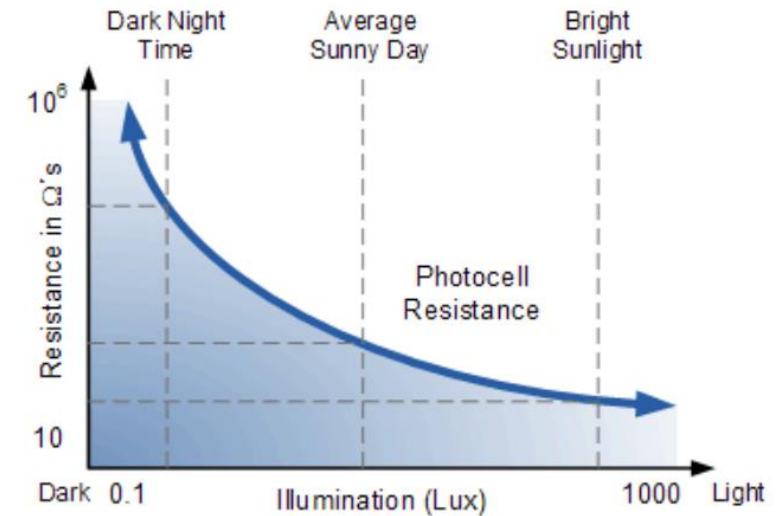
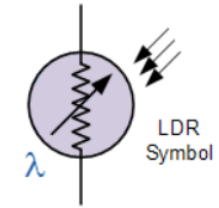
- thin film transistors



Light sensing elements

■ LDR

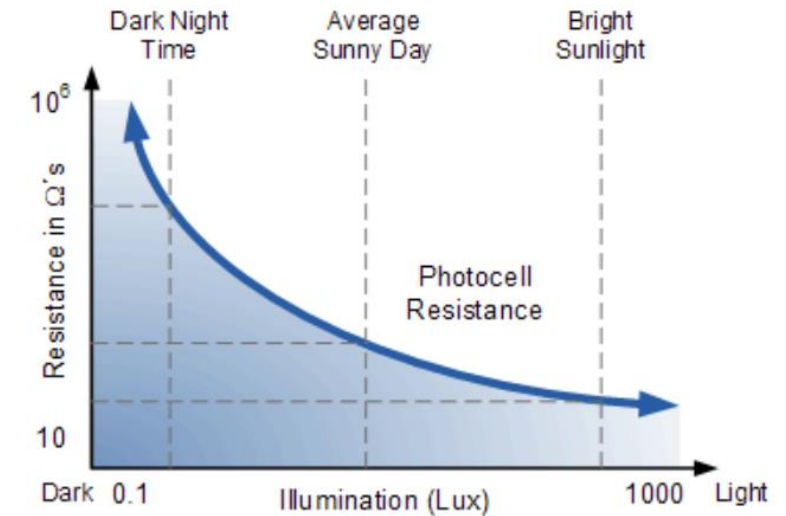
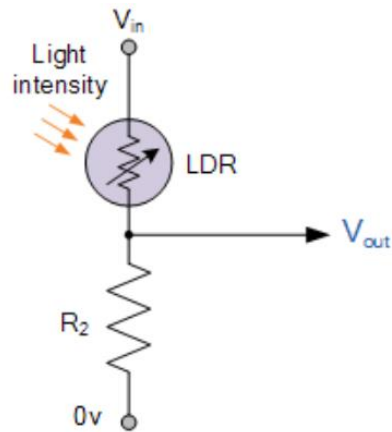
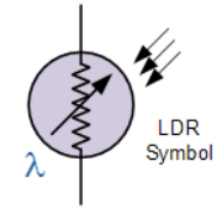
- light dependent resistor
- cadmium sulphide (CdS)
- long response time
- alarm detector?



Light sensing elements

■ LDR

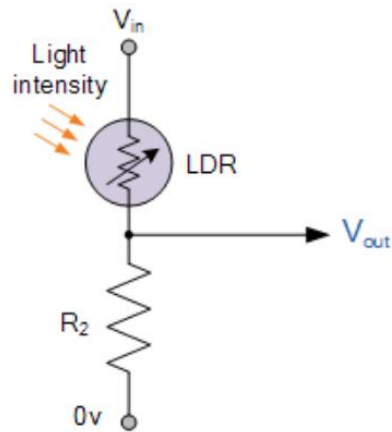
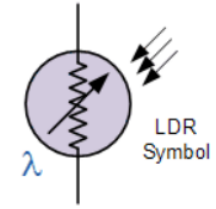
- light dependent resistor
- cadmium sulphide (CdS)
- long response time
- alarm detector?



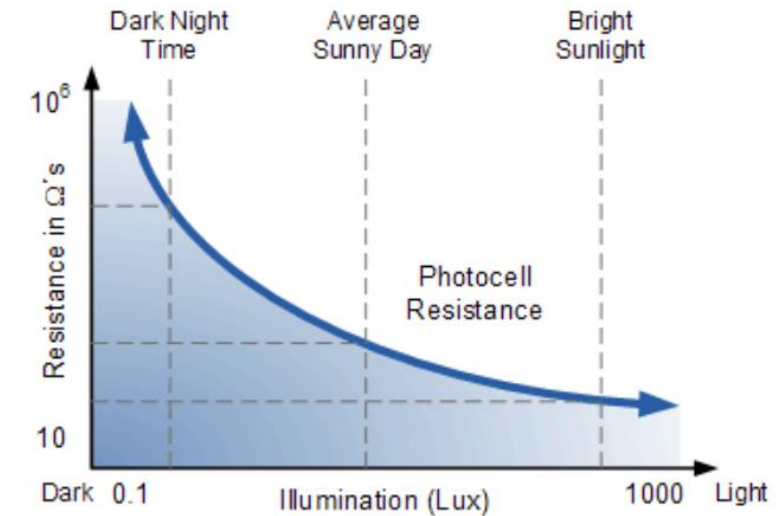
Light sensing elements

■ LDR

- light dependent resistor
- cadmium sulphide (CdS)
- long response time
- alarm detector?



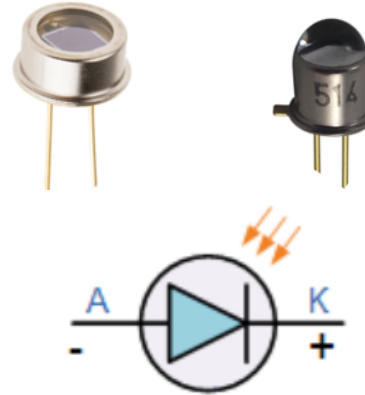
$$V_{out} = V_{in} \frac{R_2}{R_2 + R_{LDR}}$$



Light sensing elements

- Photodiode

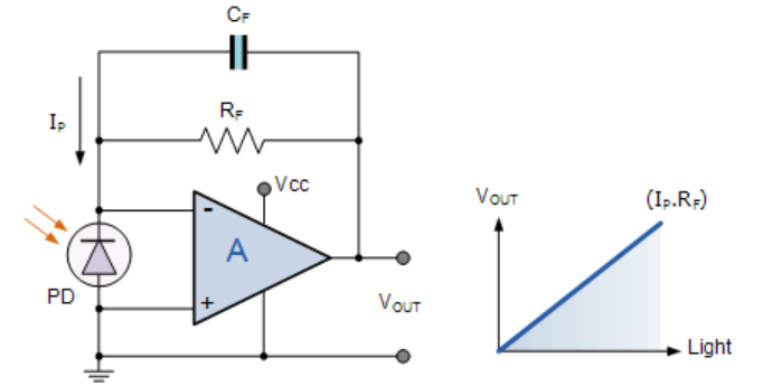
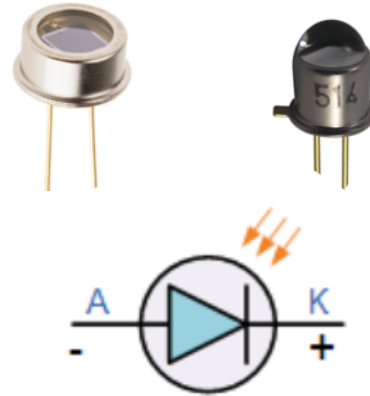
- usual PN junctions
- more responsive to longer λ (IR)
- response time: nanosec
- cameras, scanners, fax machines, light meters, DVD drives



Light sensing elements

■ Photodiode

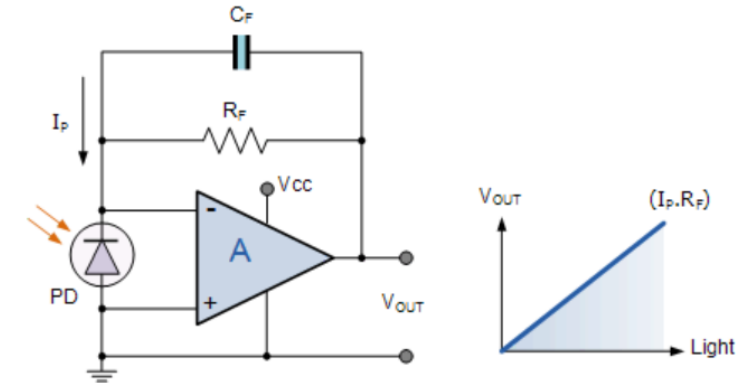
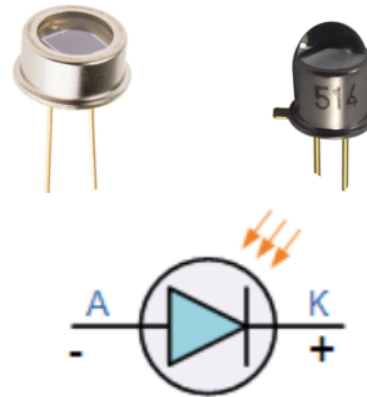
- usual PN junctions
- more responsive to longer λ (IR)
- response time: nanosec
- cameras, scanners, fax machines, light meters, DVD drives



Light sensing elements

■ Photodiode

- usual PN junctions
- more responsive to longer λ (IR)
- response time: nanosec
- cameras, scanners, fax machines, light meters, DVD drives



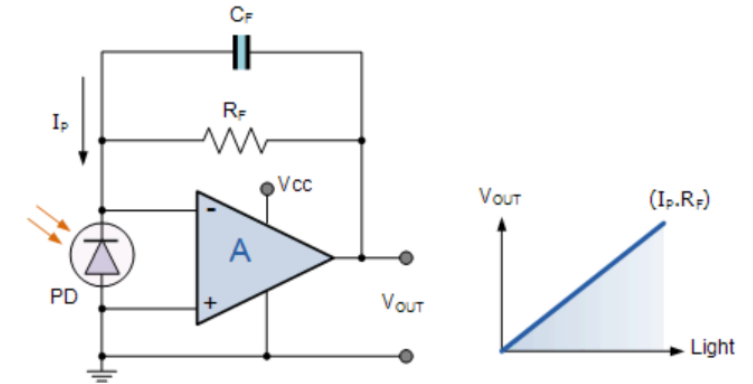
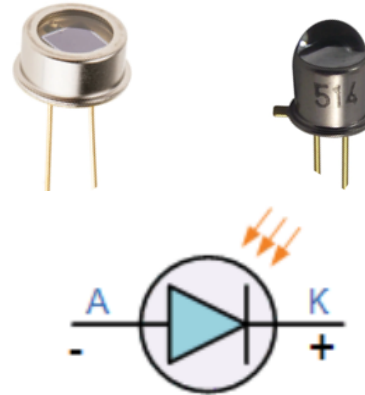
■ Phototransistor

- e.g. photodiode with inbuilt amp.
- 100times more current gains than photodiodes
- bipolar NPN transistor with optional base
- opto-isolators, opto-switches fibre optics

Light sensing elements

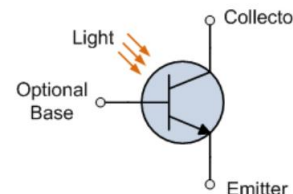
■ Photodiode

- usual PN junctions
- more responsive to longer λ (IR)
- response time: nanosec
- cameras, scanners, fax machines, light meters, DVD drives



■ Phototransistor

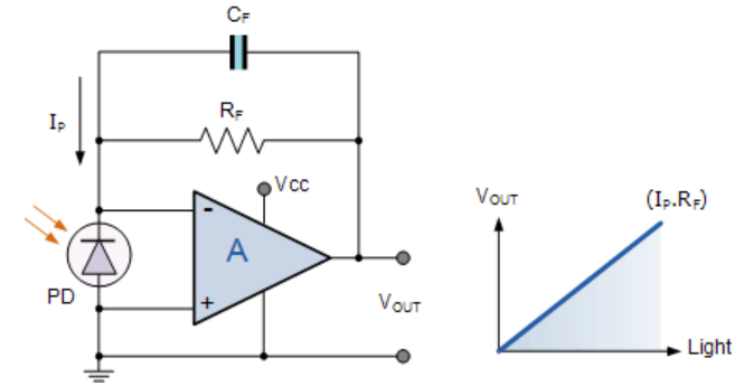
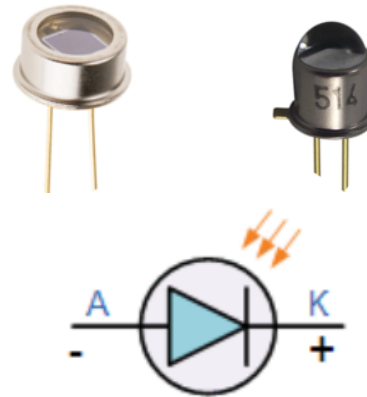
- e.g. photodiode with inbuilt amp.
- 100times more current gains than photodiodes
- bipolar NPN transistor with optional base
- opto-isolators, opto-switches fibre optics



Light sensing elements

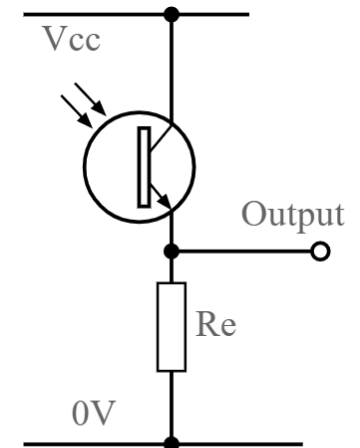
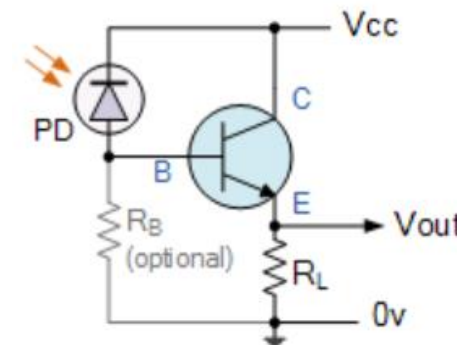
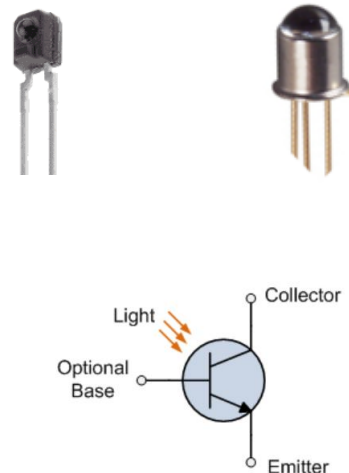
■ Photodiode

- usual PN junctions
- more responsive to longer λ (IR)
- response time: nanosec
- cameras, scanners, fax machines, light meters, DVD drives



■ Phototransistor

- e.g. photodiode with inbuilt amp.
- 100times more current gains than photodiodes
- bipolar NPN transistor with optional base
- opto-isolators, opto-switches fibre optics



Signal amplification

- High ISO
 - increased brightness sensitivity
 - better lowlight shots
 - reduced dynamics range
 - reduced color accuracy



Signal amplification

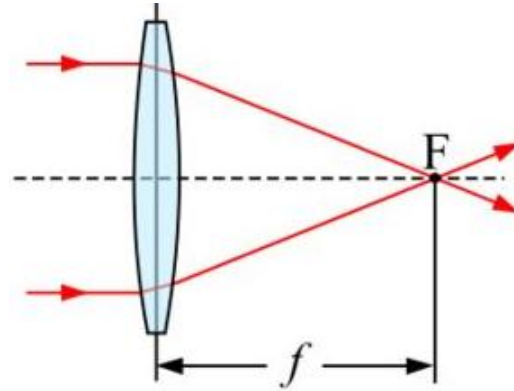
- High ISO
 - increased brightness sensitivity
 - better lowlight shots
 - reduced dynamics range
 - reduced color accuracy



Light focusing element

- Lens

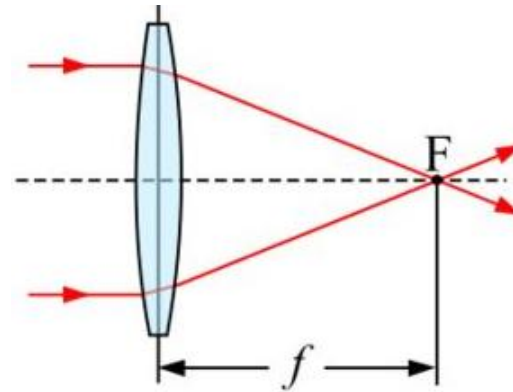
- Lensmaker's eq



Light focusing element

- Lens

- Lensmaker's eq



$$\frac{1}{f} = (n - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n - 1)d}{nR_1R_2} \right]$$

f is the focal length of the lens

n is the [refractive index](#)

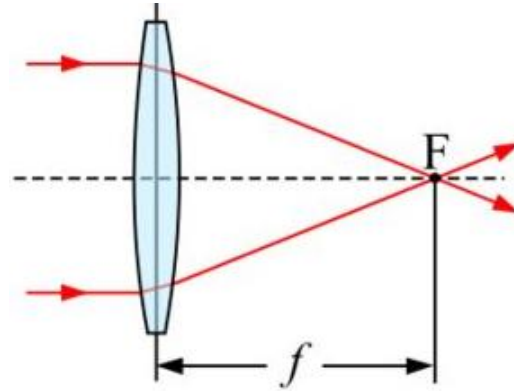
R_1 R_2 radius of curvature

d is the thickness of the lens

Light focusing element

- Lens

- Lensmaker's eq



$$\frac{1}{f} = (n - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n - 1)d}{nR_1R_2} \right]$$

f is the focal length of the lens

n is the [refractive index](#)

R_1 R_2 radius of curvature

d is the thickness of the lens

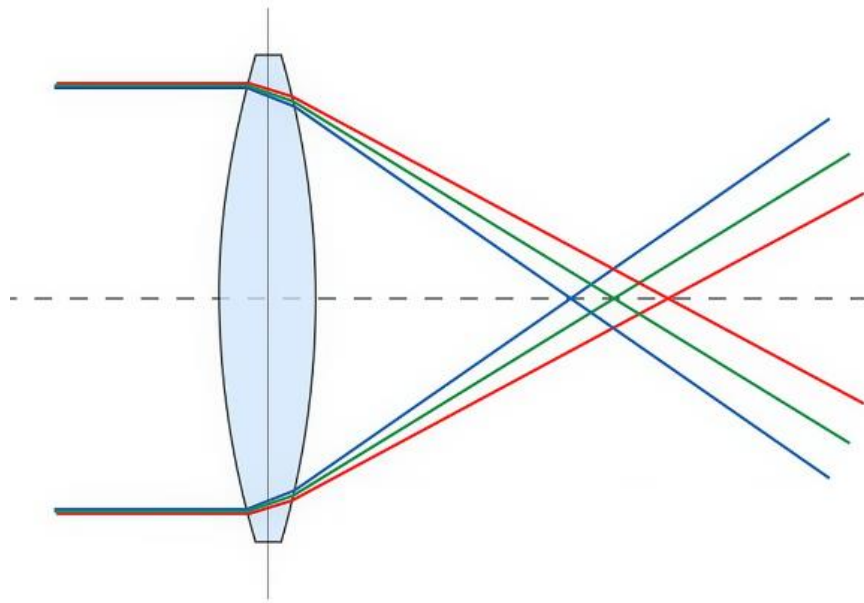
A, B : material constants.

- Refractive index

$$n(\lambda) = A + \frac{B}{\lambda^2}$$

Single lens

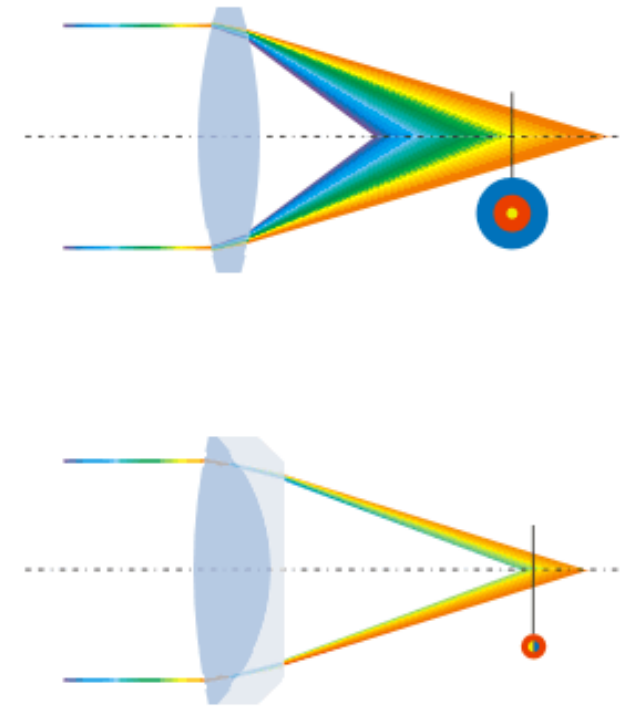
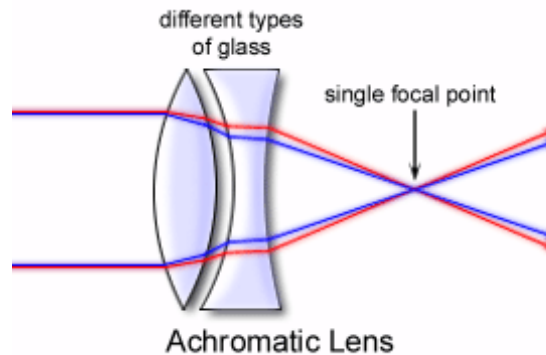
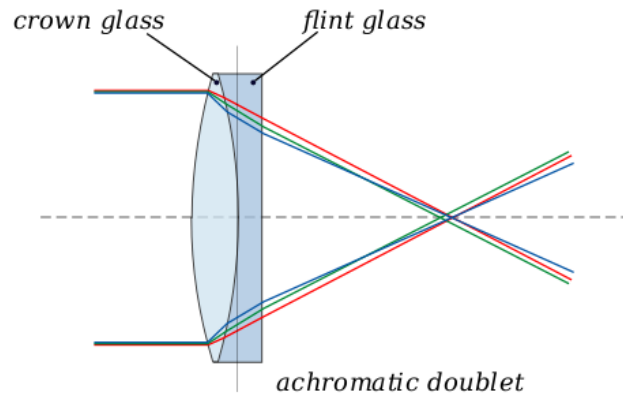
- Chromatic aberrations
 - failure of lens to focus all colors to the same point
 - fringes of color at image boundaries



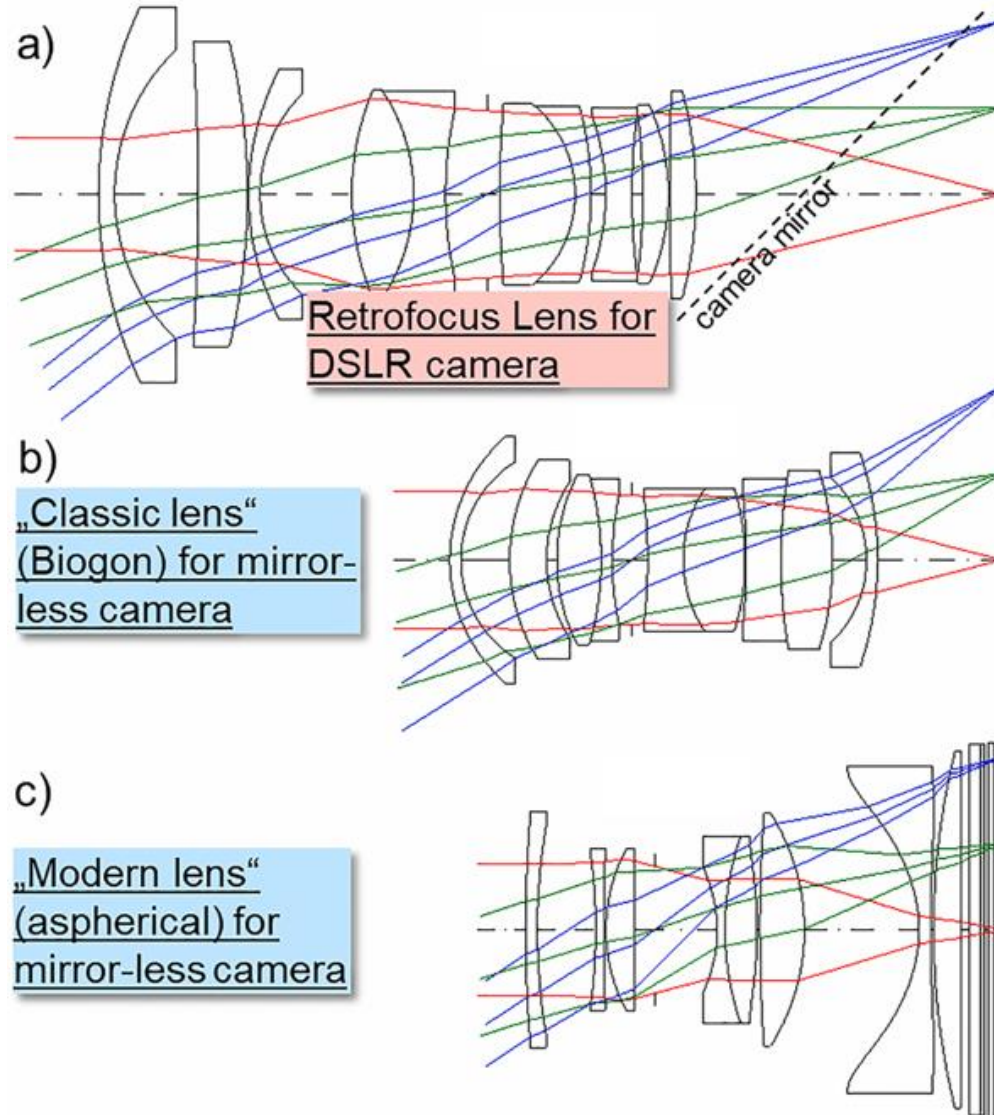
Double lens

- Achromatic doublet

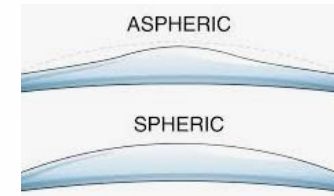
- Littrow doublet : $R_1 = R_2, R_3 = -R_2$
- Fraunhofer doublet: small air between R_2, R_3
 - more degree of freedom in design



Multi-Lens



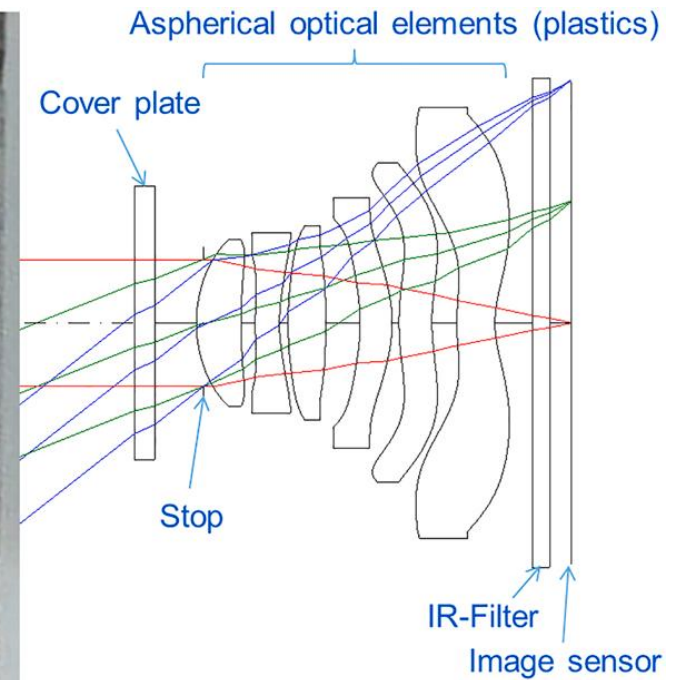
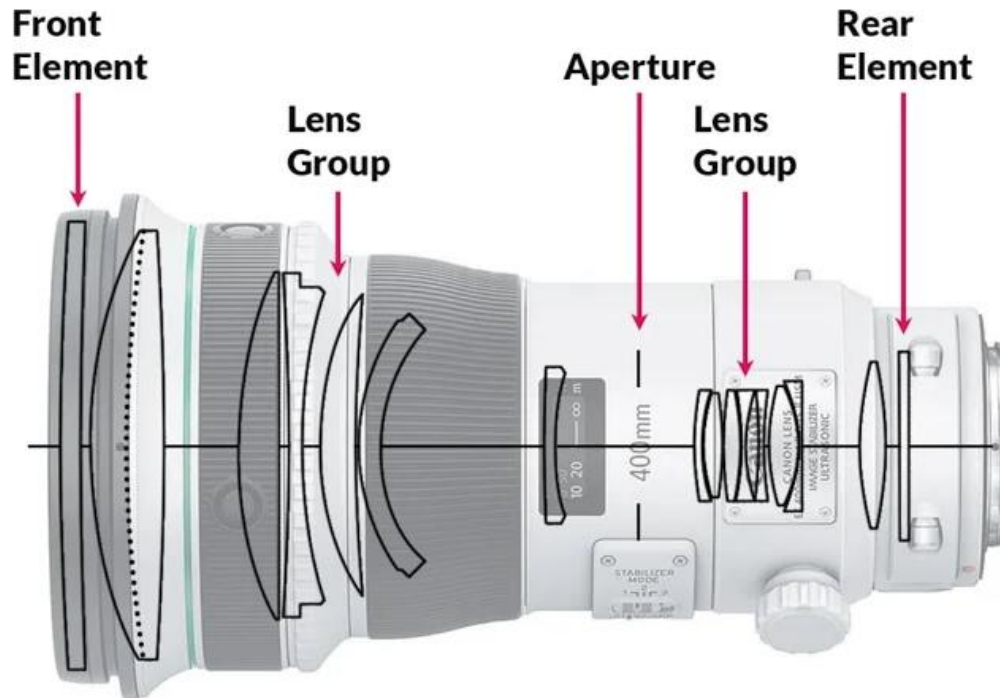
DSLR (digital
single line reflex)



**mirror-less
system
camera**

Cameras

- Eagle Vs Hummingbird



High precision lens

- Scientific and precision imaging



Image sensing

- Array sensor

- 1D, 2D

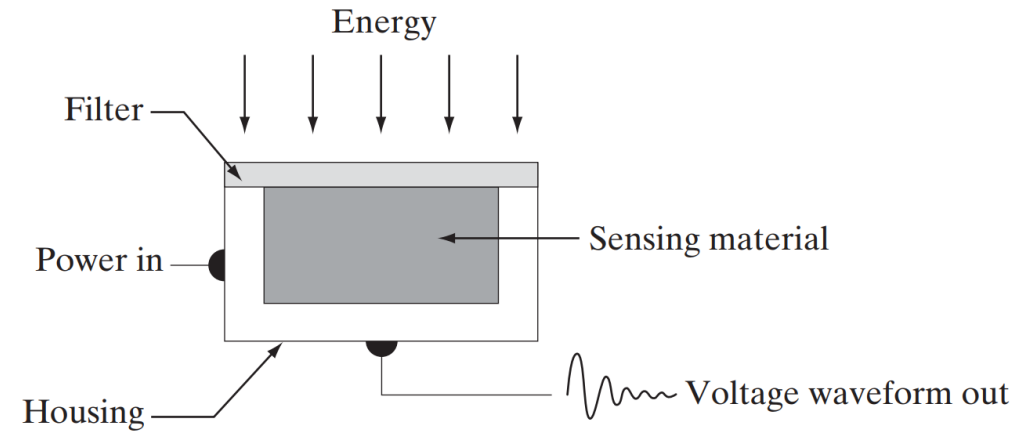


Image sensing

- Array sensor

- 1D, 2D

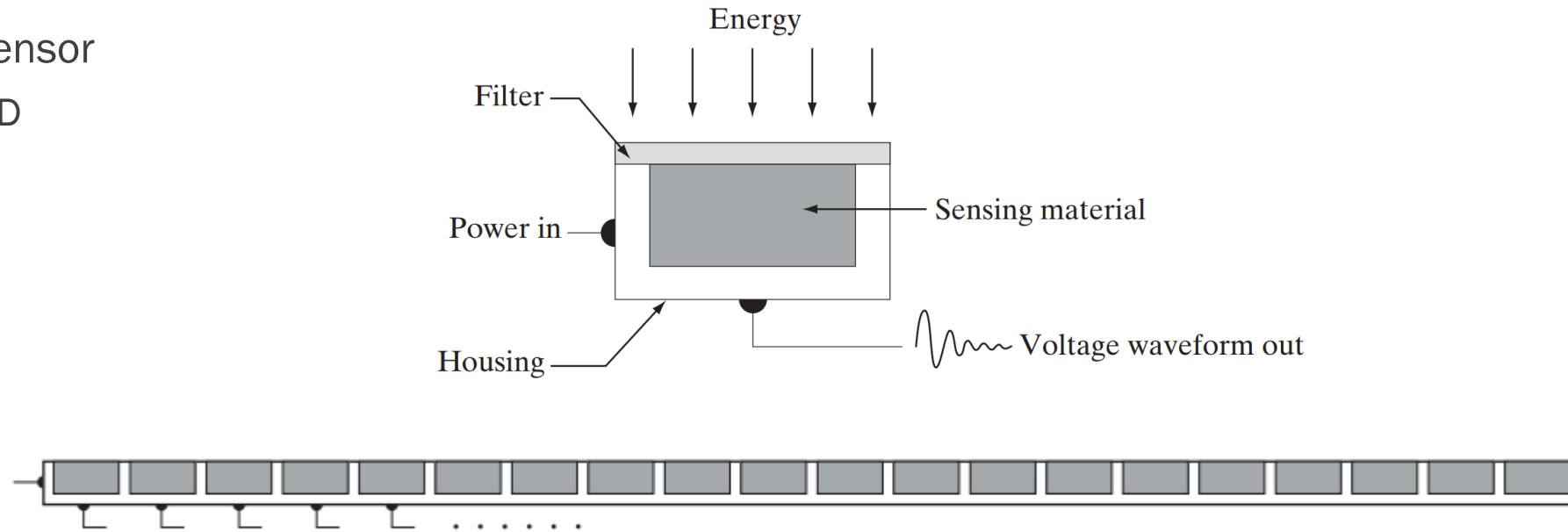


Image sensing

- Array sensor

- 1D, 2D

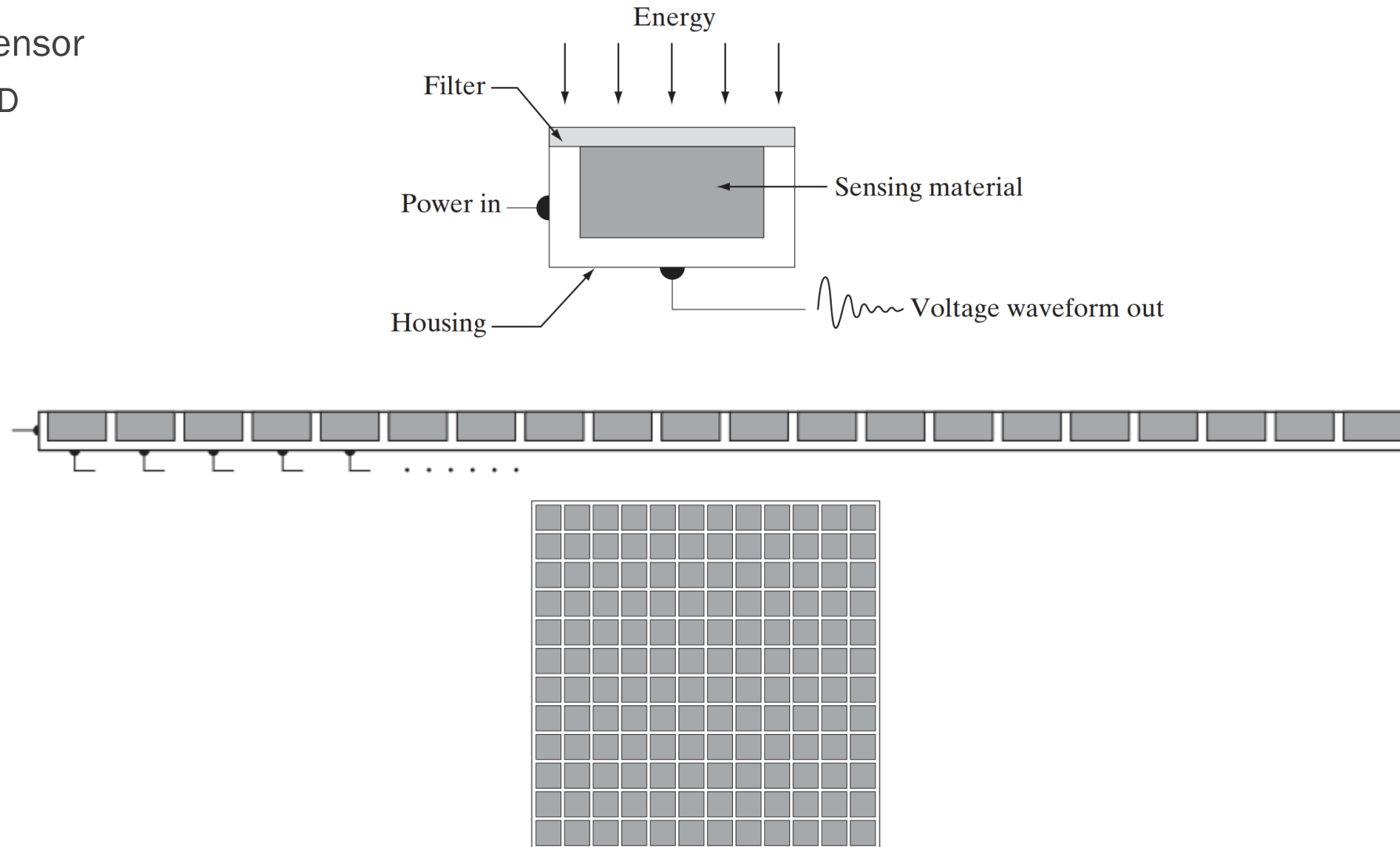
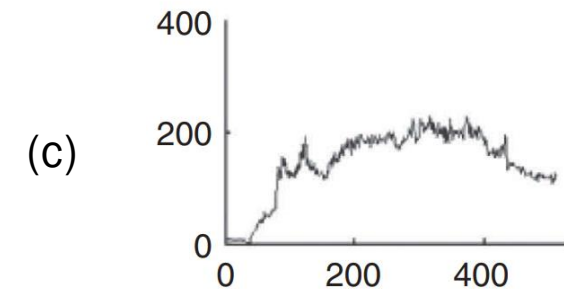
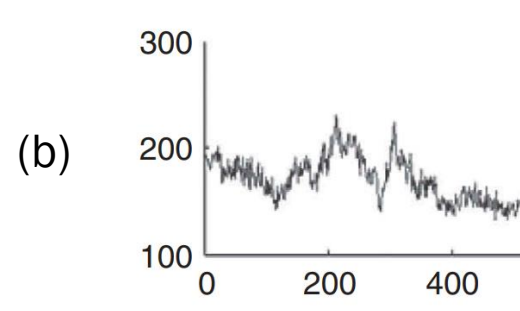
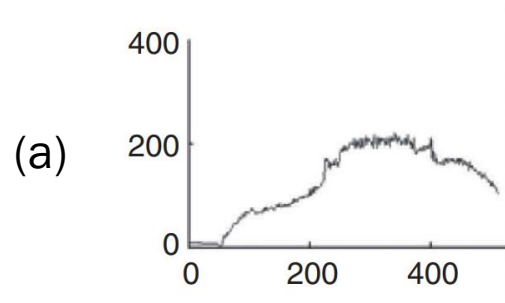
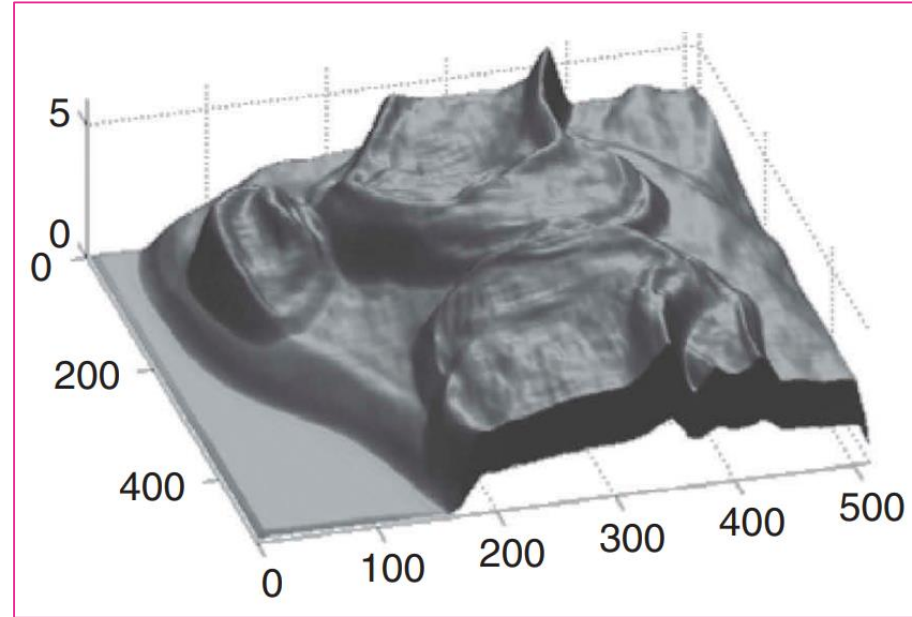
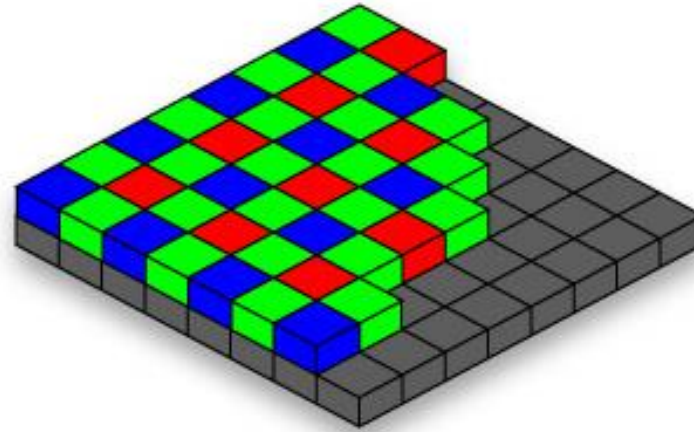


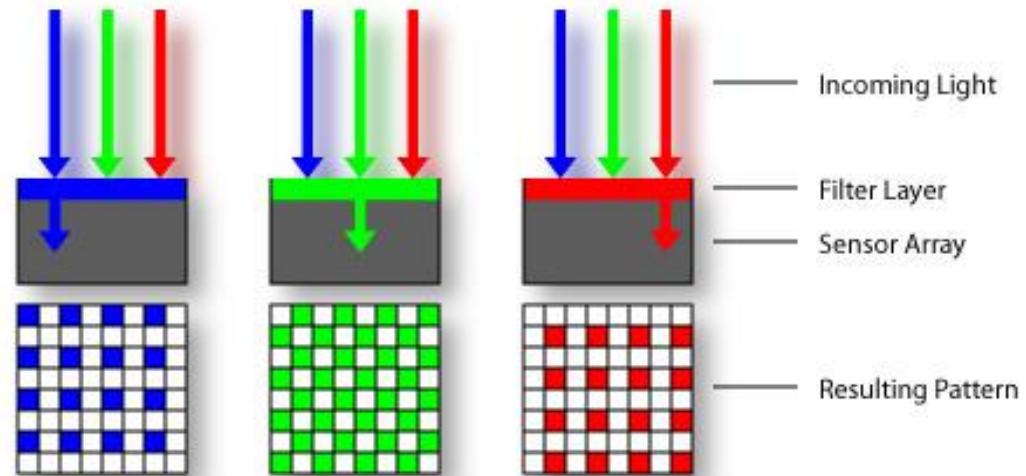
Image representations



Color sensing



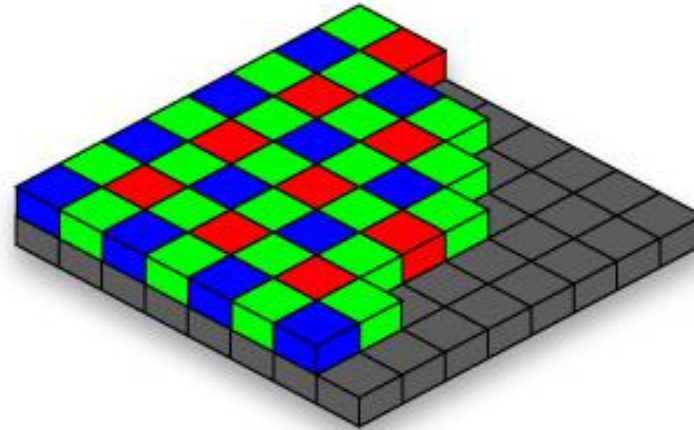
Bayer pattern



Color sensing



Estimate the color



Bayer pattern

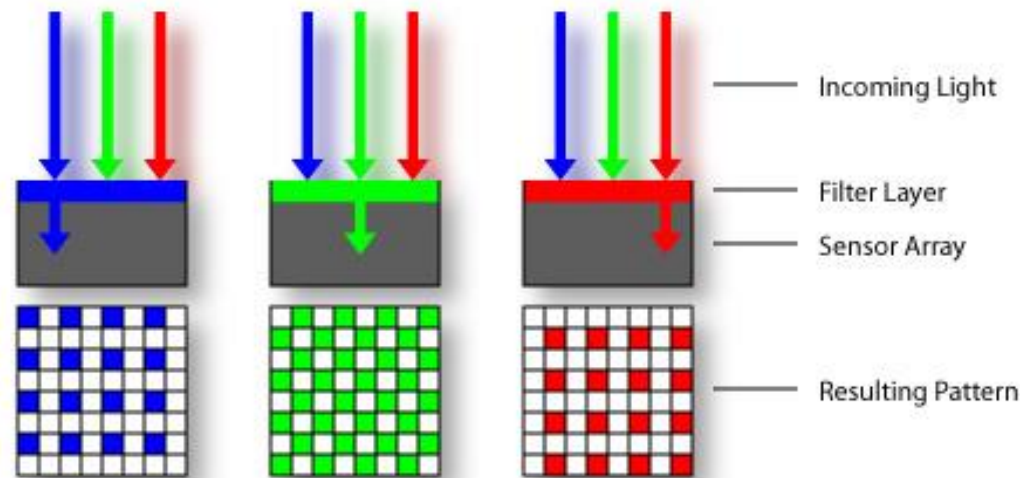
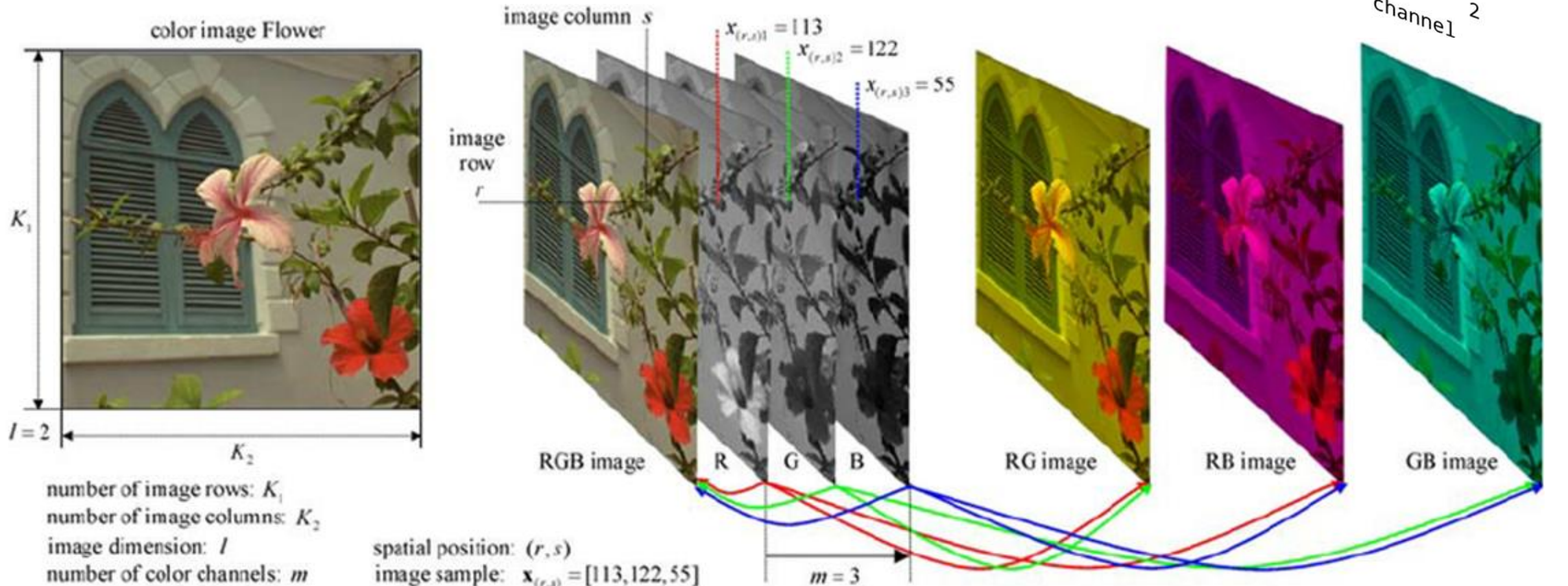


Image representations

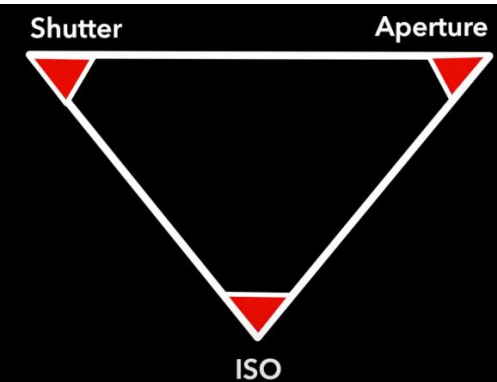


credit: K. Plataniotis

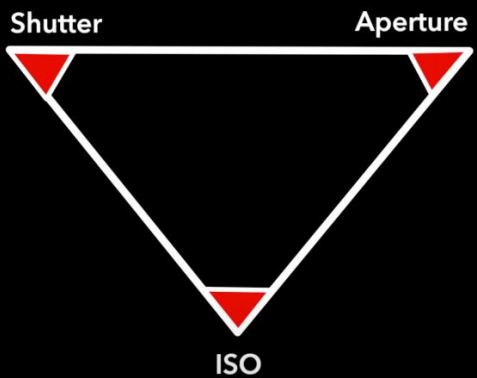
□ The Exposure Triangle



□ The Exposure Triangle



□ The Exposure Triangle



■ The Exposure Triangle

1/4 sec

1/8 sec


1/15 sec

1/30sec

1/60 sec

1/125 sec

1/250 sec




f/8

f/5.6

f/4

f/2.8

f/2



Shutter

Aperture


ISO



■ The Exposure Triangle

100 200 400 800 1600 3200 6400

1/4 sec 1/8 sec 1/15 sec 1/30sec 1/60 sec 1/125 sec 1/250 sec




f/8

f/5.6

f/4

f/2.8

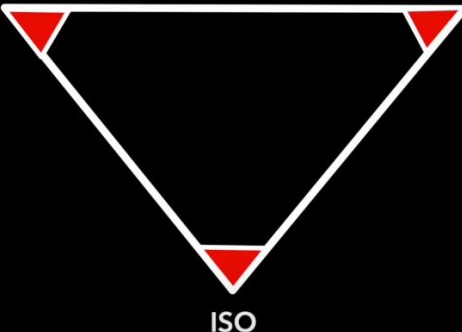
f/2



Shutter

Aperture

ISO





Conclusion

- Camera systems
- Image representation

Conclusion

- Camera systems
- Image representation

❑ Camera systems

- Aperture
- Lens
- Shutter
- Light sensors

❑ Digital image representation

- Grey
- Color
- Matrix (tensor)